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HATCHING A THEORY OF INCUBATION EFFECTS

Technical Report AIP - 98

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Pittsburgh, PA 15213

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ABSTRACT

Does putting a problem aside "to incubate" really help, and if so, why?

We address this question through a review of the literature on incubation that includes discussion of the four stage theory of creative thought (Wallas 1926), the distinction between conscious and unconscious work, and an in depth look at the cognitive mechanisms that might underlie incubation effects. A critical examination of the experimental studies on incubation reveals a wide range of findings -- some in apparent contradiction. We argue that this apparent confusion results mostly from a failure to consider the interaction of factors affecting incubation. These factors include the nature of the primary and interpolated tasks, the length and timing of the interruption (incubation period), and individual differences in the knowledge and abilities of subjects. Progress, towards understanding incubation may depend upon developing a unified theory -- one that will take into account the interactions of the different factors in a consistent and principled way. We offer one such unified theory as an example, illustrating how a unified approach might account for the existing empirical literature on incubation including several previously puzzling results.

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Does putting a problem aside to incubate really help, and if so, why?

We address this question through a review of the literature on incubation that includes discussion of the four stage theory of creative thought (Wallas, 1926), the distinction between conscious and unconscious work, and an in depth look at the cognitive mechanisms that might underlie incubation effects. A critical examination of the experimental studies on incubation reveals a wide range of findings -- some in apparent contradiction. We argue that this apparent confusion results mostly from a failure to consider the interaction of factors affecting incubation. These factors include the nature of the primary and interpolated tasks, the length and timing of the interruption (incubation period), and individual differences in the knowledge and abilities of subjects. Progress, towards understanding incubation may depend upon developing a unified theory -- one that will take into account the interactions of the different factors in a consistent and principled way. We offer one such unified theory as an example, illustrating how a unified approach might account for the existing empirical literature on incubation including several previoulsy puzzling results.

The great Greek mathematician Archimedes was asked by his patron to determine whether a crown was made of pure gold. The gold crown had been given to the king as a gift, and the king suspected that the gold had been mixed with silver. Archimedes at once recognized that if the volume of the crown could be determined, it could be weighed against an equal volume of pure gold, and its purity determined. Unfortunately, the crown was irregular in shape, and Archimedes could think of no way to determine its volume short of melting the whole thing down into some regular shape such as a rectangular brick. This, of course, was out of the question.

Frustrated, Archimedes put the problem aside and went about his daily affairs, which happened to include taking a bath. As he lowered himself into the tub, Archimedes noticed the bath water rise, and it suddenly occurred to him that the displacement of the bath water must be exactly the same as the volume of his body. Immediately he saw the solution to the problem of determining the volume of the crown. He need only drop the crown into a tank of water and measure the displacement of water. Legend has it that Archimedes was so elated by his sudden discovery that he leapt out of the bath and ran naked through the streets shouting Eureka! (I have found it!).

Stages in Creative Thought

This story is of interest partly because it illustrates several important stages in creative thought that have been described by Hemholtz (1896), Wallas (1926), Patrick (1935), Hadamard (1945), and others (e.g., Glass & Holyoak, 1986). These stages are preparation, incubation, illumination, and verification.

First, Archimedes worked on the problem, trying all of the obvious approaches until he gave up in frustration. During this **preparation** stage, Archimedes thoroughly encoded the problem so that he could call it to mind at will. Had he solved the problem during these initial attempts, most likely he would have considered the problem routine. One gauge of the novelty of a problem is its resistance to the problem solver's readily available stock of problem-solving methods.

The act of putting the problem aside and carrying out other activities is the hallmark of the **incubation** stage. Archimedes's decision to abandon the problem temporarily and go on with his daily routines marks the beginning of the incubation stage in our story. More formally, incubation can be defined as any interruption of conscious problem solving that later appears to have aided in attaining the solution. Exactly what (if anything) goes on during this period will be a major concern of this paper.

The incubation stage typically ends abruptly with a sudden insight into the problem's solution. This

illumination stage is quite rapid, and is often described as a "flash of insight." Connecting the observation of the rising bath water (and its implications) with the crown problem constitutes the activity occurring during the illumination stage in the story above.

Presumably, Archimedes eventually found some clothes and set about the practical task of actually applying his insight. This action would correspond to the fourth and final stage of creative thought, **verification**. During the verification stage, the idea is tested and final details are worked out.

Apart from the fact that Archimedes's insight establishes a precedent for these stages of creative thought dating to 30 B.C.,[1] the story is interesting because of what it does not tell us. Specifically, it tells us nothing about the processes underlying insight, or what might be occurring during the period of incubation. It is precisely this lack of information about underlying mechanisms that has led to a wide variety of theoretical proposals. Unfortunately, most of these proposals are based solely upon anecdotal evidence, with different theorists sometimes using the same anecdotes to support different claims!

A limited amount of controlled experimentation has been conducted, however. After reviewing the range of theories about incubation, we will focus on these controlled experiments and their theoretical implications.

Theories of Incubation

Historically, theories of incubation have been divided into those postulating Unconscious Work and those relying on Conscious Processing to account for incubation effects. The Unconscious Work viewpoint holds the unconscious responsible for work resulting in sudden illumination. The alternate viewpoint is that incubation can be explained in terms of conscious work on the problem during the incubation interval. A third approach is to explore the mechanisms underlying incubation to determine whether the debate over unconscious and conscious problem solving might be resolved once these mechanisms have been specified. Each of these three views will be discussed in turn, but we will concentrate on the last which seems best able to explain the empirical literature on incubation.

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[1] *Greek scholars have traced the origins of the Eureka! story* at least as far back as Vitruvius. While the story may not be literally accurate, it "help(s) us to a conception of the most original mathematician of antiquity" (Heath 1912).

Unconscious or Conscious Work?

Poincare (1913), Wallas (1926), Patrick (1937), Hadamard (1945), and Eindhoven and Vinacke (1952) are all supporters of the Unconscious Work viewpoint. In addition, the accounts of creative discovery compiled by Ghiselin (1952) and the practical advice contained in books such as Osborne's (1953) *Applied Imagination* suggest that Unconscious Work is the popular common-sense explanation for incubation. This view is intuitively appealing. Most of us have had the experience of attaining insight "out of the blue" when we were not thinking about the problem. Since we are unaware of how we arrived at the insight, we attribute our insight to the workings of the unconscious.

Poincare's essay, *Mathematical Creation* (Ghiselin, 1952), is typical of the attempts to describe the Unconscious Work hypothesis. First he notes:

> **Most striking at first is this appearance of sudden illumination, a manifest sign of long, unconscious prior work. The role of this unconscious work in mathematical invention appears to me incontestable... (Ghiselin 1952, p.27)**

Then after remarking upon the benefits of interruption of conscious work on difficult problems, he sketches his view of the unconscious process:

> **It might be said that the conscious work has been more fruitful because it has been interrupted and the rest has given back to the mind its force and freshness. But it is more probable that this rest has been filled out with unconscious work and that the result of this work has afterward revealed itself to the geometer... (Ghiselin 1952, p.27)**

When it comes to specifying the precise nature of the unconscious work, Poincare becomes quite tentative in offering a number of hypotheses. Each hypothesis has the "subliminal self" automatically forming combinations of ideas. His preferred hypothesis seems to be that the unconscious forms only combinations of those ideas that have first been "mobilized" by previous conscious work.

At the other extreme from Poincare's hypothesis of unconscious work is the view that problem solving progresses exclusively via conscious work. It may be that individuals work consciously on a problem periodically during a long incubation period. These work episodes may be brief, and, if they are not successful, they might easily be forgotten. Or, more intriguingly, perhaps they were never encoded as episodes of conscious work at all.

For example J.E. Teeple, one of the scientists responding to Platt & Baker's (1931) questionnaire on creative thinking, proposed:

...In deep concentration on any subject you are not only unconscious that you are thinking, but you are unconscious of everything else around you, and I am reasonably sure that if a man is conscious that he is thinking, then at that moment he is not doing any serious thinking.
... If [the mind] works until the solution comes, we are liable to forget that it has worked at all. I have had such revelations come, for example, in my berth in a Pullman, reading a detective story, but on one occasion I checked this, happening to know something of the time involved and the story I was reading, and I had been looking at the same page for close to three-quarters of an hour without seeing anything at all. These are not revelations any more than any solution of a problem you are working on is a revelation. (Platt and Baker 1931, p. 1986-1987)

While the accuracy of this report is certainly open to debate, its contents raise an important issue. The historical distinction has been between work done requiring conscious attention and work that is automatically done by the unconscious. What Teeple suggests is that attention can be so intensely concentrated on the problem that it brings about a loss of self-consciousness and a corresponding failure to remember that one has even worked on the problem. This forgetting of conscious work seems quite different from the unconscious work proposed by Poincare.

One way to understand these differences -- and indeed to approach the problem of incubation in general -- is to look for a set of mechanisms that might explain conscious work that is remembered, conscious work that cannot be recalled, and unconscious work. However, before we can provide a mechanistic explanation of the conscious versus unconscious distinction, we need to operationalize our definitions of conscious and unconscious work.

One reasonable approach would be to call **conscious** those processes that can be verbalized, and **unconscious** those that can not. Under this definition, the sequence of problem-solving steps that can be reported (either concurrently or retrospectively) would constitute conscious work. However other processes, such as those involved in retrieving an item from memory, are considered unconscious. That is, one may consciously know a fact that has been remembered, but the processes which actually retrieved the fact from memory are unconscious. Other definitions of consciousness are certainly possible, but this one has the advantage that it maps fairly well to the problem solving studies that form the bulk of the experimental literature on incubation.

Ericsson & Simon (1984) have developed a rigorous theory of verbal reports which helps clarify the unconscious versus conscious distinction. Their main claim is that only the contents of working memory can be verbalized. For example, a person might recall and verbalize a fact which was stored in long-term

memory. Certainly the person would be conscious of having retrieved the fact since it had to end up in working memory before it could be verbalized. However the person would be unconscious of the *process* of retrieving the fact. That is, because the retrieval mechanism operates independently of working memory, and only the results of the process get deposited there, the person can tell us nothing about the actual retrieval process itself.[2] Other processes that also bypass working memory, and are therefore unconscious, include forgetting and priming.

We conceive of forgetting as the decay of activation of nodes in long-term memory, while priming corresponds to an increase of activation of these same nodes. Forgetting decreases the probability that a given node will become a part of working memory, while priming increases this probability. We will argue that together these two mechanisms comprise the only unconscious components leading to incubation effects. In contrast to the suggestion that sequential problem solving behavior may take place at an unconscious level, we believe such behavior to be entirely conscious, although it may, as Teeple suggests, not be remembered. Our account of incubation will not rely much on the failure to encode conscious work, but, for the sake of completeness, we wish to sketch how such a situation might occur before discussing other mechanisms at greater length.

Briefly, the capacity of working memory is limited. New information is constantly replacing old information, making the former inaccessible to conscious report. If there is a rapid turnover of information in working memory, as would be the case in Teeple's example of intense concentration on a problem, it is quite possible that none of the intermediate results stay in working memory long enough for them to be encoded into long-term memory. The result is that after such a period of intense thought, one is left with the answer (the latest contents of working memory) with no idea of how one arrived at this answer. In such a case, it would be an understandable mistake to attribute the result to unconscious work. In fact, one simply has no recollection of the conscious work that took place because the intermediate states did not stay in working memory long enough to get encoded in long term memory.

Ericsson & Simon point to results in a number of well known experiments (e.g., Duncker, 1945; de Groot, 1965; Maier, 1931) supporting the contention that intermediate results may be unreportable if they cause the direct execution of other processes that make full demands on working memory (Ericsson &

[2]Note, however, that if the eventual retrieval of the fact depended on the retrieval of several intermediate cues, each of which entered working memory, such cues could be reported. It is only the process that carried out the actual retrieval of each of these cues that is unconscious.

Simon, 1984, p. 159-160).

Mechanisms

One approach to finding a set of mechanisms sufficient to account for incubation effects is to examine systematically the factors that cognitive psychology tells us can act over time. From running experiments for example, we know that such factors as history, maturation, and statistical regression, can affect the results (Campbell & Stanley 1963). We can ask what the mechanistic analogues to these threats to the internal validity of an experimer ht be in the domain of incubation effects.

History : Priming

History is an excellent candidate for explaining incubation. Between the time work is stopped on a problem and when work is resumed, the problem solver may have any number of seemingly unrelated experiences that later prove to be of help in solving the problem. In anecdotal accounts of incubation, these related experiences play the role that Archimedes' bath did in his attainment of insight.

For example, Koestler (1964) tells how Benjamin Franklin originally wanted to test his theory that lightening was electricity by affixing a lightening rod to a tall spire he hoped would be erected in town. The construction of the spire was delayed, and Koestler hypothesizes that the thoughts of a frustrated Franklin may have turned toward relaxing memories of his childhood. One of these was the memory of floating on his back in the lake for hours (the young Franklin was a phenomenal swimmer) while being towed by a string attached to a kite. Here, in the memory of kites and childhood bliss, Koestler says Franklin found the germ that grew into the idea of sending a kite into an electrical storm. Incubation effects occurred because Franklin took time away from the problem that allowed him to access experiences which would not have come to mind during normal work on the problem, but which none the less proved relevant.

Experimental studies demonstrating the effectiveness of hints (Burke, 1969; Maier, 1930) and incidental cues (Judson et. al., 1956; Mendelsohn & Griswold, 1964) support the view that apparently irrelevant events can affect problem-solving behavior -- sometimes without the solver being able to later recall the hint or cue. Some researchers have suggested spreading activation as a mechanism that might account for effects of this kind (Langley & Jones, 1988; Yaniv & Meyer, 1987). We believe that spreading activation falls under the general label of priming.

Maturation: Fatigue, Forgetting, and Growth

Maturation, broadly conceived, encompasses "all of those biological or psychological processes which systematically vary with the passage of time, independent of specific external events" (Campbell & Stanley, 1963, p.7-9). Certainly included here is the fatigue hypothesis. Poincare's intuitions notwithstanding, if one works on a problem until exhaustion, subconscious processing need hardly be invoked to explain better performance after a good rest. Indeed, as Posner (1973) points out, some of the earliest accounts of incubation (e.g. Hemholtz) credit the fatigue hypothesis as an explanation of incubation.

Forgetting is another psychological process that falls under the heading of maturation. One theory, which originated with Woodworth (1938) and has been elaborated substantially by Simon (1966), suggests that incubation is a period of time when the irrelevant details of the problem are forgotten. Hence, when the solver returns to the problem, it is with an unbiased mind. The approaches that failed previously are not tried again. The perseveration that may have been blocking a successful problem-solving attempt is broken and the problem solver is free to try new ideas. Presumably, however, not everything has been forgotten. In particular, the problem-solver is likely to have learned some new and potentially useful facts from struggling with the problem.

Before the incubation period, the working memory of the problem-solver was crowded with the specifics of useless approaches. The forest could not be seen for the trees. However, after incubation, as the problem-solver starts fresh, the forest looks different from the way it did on the first approach to the problem. The difference stems from the additional knowledge that the problem-solver has gleaned from his or her earlier struggles.

Maturation can also be interpreted in the more common sense of the word -- growth over a long period of time. Many famous discoveries appear to have been incubated for years (Koestler, 1964). In some cases, the initial attacks on a problem may have been unsuccessful simply because the problem solver lacked the experience that was accumulated over the successive years. The same argument can be applied to biological maturation, though the specifics seem less clear in this case.

Statistical Regression

Regression toward the mean is a final potential explanation of incubation. If the first attempt at solving the problem is unsuccessful because the problem solver is performing below his or her normal ability level, one would expect subsequent attempts to be more successful because of regression. In this

account, incubation simply reflects that people have good days and bad days. A bad day followed by a good day is likely to look like incubation. Assuming that the factors determining good and bad days could be specified, this explanation might account for many of the anecdotal accounts of incubation effects. However, since most of the experimental studies compared mean performance of groups of subjects, presumably regression would not be an explanation for the results that will be discussed here.

Experimental Studies of Incubation

Whereas anecdotes are plentiful, replicable experimental evidence of incubation is in short supply. In fact, some researchers have questioned whether there is adequate experimental evidence to demonstrate the phenomenon at all (Olton, 1979). In view of this possibility, the first step in organizing a review of the experimental literature on incubation is to examine whether the effect exists.

Of the 17 studies we have identified as directly testing incubation effects, 11 found an incubation effect (i.e., a beneficial effect of an interruption on problem solving relative to a continuous-work control condition) in at least some conditions. Another four reported incubation effects but defined incubation differently, namely, as recurrence of ideas that were abandoned earlier in a problem-solving episode (Eindhoven & Vinacke, 1952; Patrick, 1935, 1937, 1938). Of the remaining two, one study found the continuous-work control group to do consistently better than all but one of the interrupted groups (Gall & Mendelsohn, 1967). The other failed to find incubation effects of any kind (Olton & Johnson, 1976).[3]

In addition, as Olton (1979) points out, there have been reports of failures to replicate results across laboratories. For example, Silveira (1971) reports failing to replicate the results of Fulgosi and Guilford (1968). However, Fulgosi and Guilford (1972) reported an incubation effect for a task quite similar to the one used in their earlier study, one year after Silveira's failure to replicate. Interestingly, Olton (1979) reports that he was unable to replicate Silveira's results, despite that fact that Silveira (1971) found a consistent incubation effect across a series of different experiments. Olton and Johnson (1976) also report a failure to replicate an earlier study by Dreistadt (1969).

There are two ways to look at these reported failures to replicate. We might consider them an indictment of incubation. After all, three failures to replicate together with the studies that failed to find any evidence of incubation seem significant, given the small total number of studies. If we assume, as is likely, that publication bias works against reporting null effects, then the actual number of failures to find incubation may be even larger.

On the other hand, the bulk of the limited experimental literature is positive. Rather than dismiss incubation completely, we argue that a more complete understanding of the factors affecting incubation is

[3]Olton (1979) cites two additional studies that failed to find an incubation effect: Olton (unpublished) and Dominowski (1972). However, neither of these papers has been published (to our knowledge), and hence they were unavailable for review.

needed.

Manipulation of Factors

Factors that potentially affect incubation include the type of primary task used, the timing and length of the interruption period, the nature of the activity performed during the interruption period, and individual differences in subjects' abilities and knowledge.

Typically, there is at least one control group that works continuously on the problem. The experimental groups may be subjected to interruptions of varying lengths and the timing of the interruption is often varied as well. Sometimes subjects know that they will be returning to the initial problem after the interruption, sometimes not. The nature of the interruption is perhaps the most critical variable. Subjects may be asked simply to rest or to take a non-specific break (e.g., "read a book" or "go shopping"). Alternatively, subjects may be required to perform a second attention-demanding task (e.g., the Stroop task) during their break. The rationale for such a task is that it presumably allows no time for subjects to think about the first problem during their incubation period. Still other studies provide unwitting subjects with subtle hints or incidental cues during their interruption period. The cues may be disguised as answers to an apparently unrelated intervening task. To make sense of the empirical literature on incubation, we must understand the effects of the primary task and each of these manipulations. However, we should also keep in mind that it may ultimately be necessary to think in terms of interactions in order to account for the diverse empirical findings.

Primary Tasks

Table 1 lists the 17 studies reviewed in this paper, the primary tasks used in each experiment the approximate length of each experiment, and whether incubation was reported. The simplest incubation paradigm is to interrupt work on the primary task for an interval of time, and then allow the subject to return to that task. In this simplest case, no attempt is be made to manipulate the nature of the interpolated activity, except, in some cases, to ensure that subjects do not consciously work on the primary task during the interruption period. That is, subjects typically perform an unrelated activity during the interruption period. In addition, no attempt is be made to manipulate the ability level of the subjects. The experiments meeting these criteria are noted as being "simple" in the last column of Table 1. In contrast, experiments that explicitly manipulated the type of activity performed during the interruption, or experiments that manipulated subjects' ability levels have been designated "complex".

Because we use are using a very specific definition of incubation, **namely an improvement in problem-solving performance following an interruption of the primary task as compared with a continuous work control group**, allowance must be made for studies that define incubation differently. Specifically, studies using different definitions of incubation (e.g. recurrence of ideas during one continuous problem solving episode) are marked N.P. (Non-Paradigmatic) in the last column of Table 1. These studies are included mainly because of their historical significance.

Table 1

Tasks used in Incubation Experiments

Study	Task Description	Experiment Length*	Design
Patrick (1935)	Poem Composition	30 min.	N.P.
Patrick (1937)	Draw Picture	30 min.	N.P.
Patrick (1938)	Design Experiment	13 min. - 3 weeks	simple
Eindhoven & Vinacke(1952)	Draw/Paint Picture	1 hr. - months	N.P.
Mednick et. al. (1964)	Remote Associates Test (RAT)	40 min.-24 hr.	complex
Gall & Mendelsohn (1967)	Remote Associates Test (RAT)	2 hours	complex
Fulgosi & Guilford (1968)	Generate consequences in "what if" scenarios	8 - 28 min.	simple
Dreistadt (1969)	Farm & Tree Problems (insight problems)	20 min.	complex
Murray & Denny (1969)	Saugstad's Ball Problem (an insight problem)	20 min.	complex
Silveira (1971)	Solve Cheap Necklace problem (an insight problem)	35 - 245 min.	simple
Fulgosi & Guilford (1972)	Generate consequences in "what if" scenarios	8 - 68 min.	simple
Dominowski&Jenrick (1972)	Maier's Hatrack Problem (an insight problem)	20 min.	complex
Peterson (1974)	anagrams	24 min.	simple
Olton & Johnson (1976)	Dreistadt's Farm Problem (an insight problem)	30 - 45 min.	complex
Beck (1979)	Brainstorm for uses of "Luminium"	24 - 54 min.	simple
Kirkwood (1984)	Group brainstorming on campus life issues	30 min.	complex
A. Patrick (1986)	Remote Associates Test (RAT)	1.75 - 2 hrs.	complex

* Length of the experiment can vary depending upon which condition subjects were in.

The first thing to notice about the tasks used in experimental studies of incubation is that, without exception, they involve thought that would be called creative. The domains include composing poems, drawing pictures, designing experiments, finding solutions to problems of campus life, thinking of remote consequences for a given hypothesis, solving puzzle problems that require physical manipulation or construction, as well as puzzles that are more abstract, solving anagrams, and producing remote or unusual responses to verbal stimuli. Nowhere do we find experimenters using tasks such as long division, which presumably require only that subjects execute a known algorithm. Instead, all investigators seem to share the belief that incubation effects will be observed only when there is the opportunity to create something new, or when something unknown must be discovered. Whatever the mechanism involved in incubation, it would seem to be limited to generating new ideas rather than to executing ideas that have already been well-formed.

A second observation is that the tasks range widely from complex, ill-defined problems (e.g. discussing ways to develop greater rapport between students and faculty [Kirkwood, 1984]) to puzzles whose answers and possible approaches are quite well-defined (e.g. anagrams [Peterson, 1974]). The tasks also vary in the amount of time allowed to complete them, ranging from 60 seconds in the case of items on the Remote Associates Test (Mednick, Mednick, & Mednick, 1964) to two or three weeks in the case of designing a scientific experiment (Patrick, 1938). However, the vast majority of tasks that have been studied for incubation effects take less than an hour to complete.

This last point often leads to the objection that laboratory studies may lack ecological validity, and that this lack poses a major difficulty for any attempted study of incubation. Although realistic studies are to be encouraged, there are at least two reasons for believing that progress can be made in the laboratory. First, the majority of published studies on incubation have found that an incubation period facilitates problem solving performance. Second, a useful explanation of incubation will most probably rest upon mechanisms that operate well within the time frame allowed by typical laboratory experiments. These mechanisms will become evident as we examine individual experiments more closely.

In short, the current literature on incubation is based primarily on creative tasks that can be solved within the time constraints of a short laboratory experiment.

Subjects' Knowledge of Returning to the Task

Do incubation effects occur only when subjects know that they will be returning to the primary task after the break in problem solving?

Fulgosi and Guilford (1968) hypothesized that subjects who expected a second chance to work on a problem would be more likely to show an incubation effect than subjects who did not. They asked subjects to generate as many consequences as possible given the questions: "What would be the results if everyone suddenly lost the ability to read and write?" and "What would be the result if none of us needed food anymore to live?". Both the number and quality ("remote" or "obvious") of consequences were judged independently (inter-rater reliability = .84) by three raters who were blind to the experimental conditions.

Subjects either worked on the task continuously for four minutes, or worked for two minutes, were interrupted for either ten or twenty minutes, and then resumed work for another two minutes. The interruption task consisted of 25 number-series problems of difficulty such that no subject completed all of the problems within the 20-minute interval. Half of the subjects in each incubation group knew that they would be returning to the consequences task after the interruption; half did not know.

Fulgosi and Guilford found that subjects in the 20-minute incubation condition generated significantly more consequences than subjects in either the continuous-work condition or the 10-minute incubation condition. Furthermore, subjects' knowledge whether they would be returning to the consequences task after an interruption did not seem to affect the results.

Dreistadt (1969) gave subjects two types of puzzle problems to solve. His control subjects worked on a puzzle continuously for 20 minutes. The experimental group worked in accordance with the following instructions:

It has been found that when trying to solve a problem, it often helps the person to solve the problem if he 'puts the problem aside' for awhile and then continues on it later. You have five minutes in which to solve the problem, then a break of eight minutes, and then seven more minutes to solve the problem. (Dreistadt 1969, p.164)[4]

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[4]Note that this design counts the interruption period as part of the total time allowed for work on the puzzle. In contrast, most other studies on incubation consider the sum of the time spent before and after the break to be the right length of time to compare with the comparative continuous work control group. Dreistadt's design is a stricter test of incubation because it assumes that the time spent during the interruption period is at the expense of time spent in continuous work on the problem.

Dreistadt found incubation effects on one problem but not on the other, suggesting that the knowledge about returning to the problem, knowledge of when the break would occur, knowledge of the length of the break, and even potential demand characteristics of being placed in an experiment where one knows the expected outcome, were not the crucial factors in bringing about incubation.

Of the remaining studies reporting incubation effects, three explicitly mentioned forewarning subjects that they would be returning to the interrupted tasks (Kirkwood, 1984; Murray & Denny, 1969; Patrick, 1938; Silveira, 1971). One (Dominowski & Jenrick, 1972) explicitly states that subjects were **not** informed that they would return to the interrupted task. Five were not specific on this point (Peterson, 1974; Mednick et al., 1964; A. Patrick, 1986; Fulgosi & Guilford, 1972). And two (Patrick, 1935, 1937) did not compare continuous work to interrupted work, so the question of subjects' knowledge of returning to the task did not apply.

Of the two studies reporting negative or null effects of an incubation period, one does not mention forewarning subjects that they would be interrupted (Gall & Mendelsohn, 1967). In the other study (Olton & Johnson, 1976), subjects were explicitly informed that they would return to work on the unfinished problem.

In sum, knowledge about returning to the interrupted task does not seem to play a role in producing (or inhibiting) incubation. Studies report incubation effects both when subjects were forewarned, and when they were not. Similarly, studies have failed to find incubation effects both when subjects had knowledge and when they did not have knowledge that they would return to the primary task. Perhaps the most telling evidence is that a study specifically designed to test the effects of differential knowledge found no differences in incubation effect (Fulgosi & Guilford, 1968). Variations in the information provided about the length and/or timing of the interruption, or even that the interruption was expected to have a positive effect, have not seemed to have significantly affected incubation.

Length and Timing of Interruption

When should a subject be interrupted on a task if incubation is to have maximum benefit and how long should that interruption be? To our knowledge, only three studies have addressed these questions directly, although an examination of the literature as a whole will provide additional information on these issues.

Silveira, who wrote her thesis on *The effect of interruption timing and length on problem solution and*

quality of problem processing, devoted some attention to these questions. She used the cheap-necklace problem as her task. The problem is as follows: "A man has 4 chains, each 3 links long. He wants to join the 4 chains into a single closed chain. Having a link opened costs 2 cents and having a link closed costs 3 cents. The man had his chain joined into a closed chain for 15 cents. How did he do it?" Silveira, 1971, p. 178). Her first experiment involved a control condition and four experimental conditions corresponding to a 2 X 2 factorial design: early and late interruption of problem solving X short and long interruption length. Silveira started timing subjects from the point where they understood the problem sufficiently so that they were able to make an attempt to solve it. Early-interruption subjects were interrupted 3 minutes after this point and were allowed to work for an additional 32 minutes upon their return to the problem. Late-interruption subjects were interrupted after 13 minutes, and allowed 22 minutes upon their return to the problem. Control subjects worked continuously for 35 minutes on the problem.

The length of the incubation for any given subject was independent of *when* he or she was interrupted. Both early- and late-interruption subjects took breaks of either 30 minutes (the Short-Interruption subjects) or 3.5 hours (Long-Interruption subjects). Of the four experimental groups (Early-Short, Early-Long, Late-Short, Late-Long), only the Late-Long subjects showed evidence of incubation when compared with the control group. This better performance of the Late-Long group compared with continuous work was replicated by Silveira in a second experiment with tighter methodological controls. Her results support the interpretation that a sufficient preparation period (13 minutes in this case) is needed before an interruption is likely to have a beneficial effect.

A second implication of Silveira's finding that her Late-Interruption/Long-Interruption groups demonstrated incubation is that longer interruptions may be better than shorter ones. This issue of the length of interruption was explicitly examined in the studies by Fulgosi and Guilford.

First we note that Fulgosi and Guilford (1968, 1972) found that only two minutes appeared to be adequate preparation time for the Consequences task. Presumably, the difference between their results and Silveira's can be explained by the discrepancy in the tasks used. While Silveira used a relatively complex problem-solving task, Fulgosi and Guilford used tasks that required only retrieving or generating ideas from memory. If we assume that the purpose of preparation is to gain familiarity with (or "chunk") the problem elements and possible manipulations (as argued by Simon, 1966), then it follows that tasks with more novel elements should require more preparation time.

With regard to the length of interruption, Fulgosi and Guilford (1968) found a 20-minute interruption interval to be significantly more beneficial than either continuous work on the problem or a 10-minute interruption. While there was a trend for the ten-minute interval to be of some benefit, it did not differ significantly from continuous work. As a test of the range of beneficial interruption lengths, Fulgosi and Guilford (1972) conducted a similar study in which they found that a 30-minute interruption was significantly more beneficial than either continuous work or a 60-minute interruption. This finding suggests that there may be an optimum length of interruption for a given task. For the short tasks used in Fulgosi and Guilford's experiments, the optimum length seem to be about 25 minutes, while in Silveira's more complex task, a 3.5-hour interruption was preferable to a .5-hour interruption.

Although the remaining experimental studies do not test the effects of length of interruption directly, we were curious to see if an examination of the literature as a whole might give us some clue as to the optimum interruption length to produce incubation effects. While the tasks vary widely in complexity, researchers hoping to find incubation usually take the complexity of the task into account when deciding how much time to allow before the interruption. In effect, there is implicit (and often explicit) agreement that incubation can only happen to the prepared mind -- a fact that Silveira has demonstrated experimentally.

Specifically, we were interested in whether there might be some consistent relationship between the amount of preparation time allowed (roughly taken as an index of the problem's complexity) and the length of the interruption period. Table 2 lists all 17 studies along with the relevant information. Studies in the first quarter of the table reported incubation effects attributable to time spent away from the problem either doing nothing or performing unrelated tasks. Studies listed in the second quarter of the table reported an incubation result only in conditions where factors other than time away from the problem were involved. These factors included receiving hints or priming, performing a related task during the interruption, and incubation effects that were observed only with subjects selected for high or low ability. Studies in the third quarter of the table reported negative or null effects of interruption in one or more conditions compared to a continuous-work control. Finally, the experimental design of studies listed at the bottom of the table did not allow a quantitative comparison of the preparation time and the interruption time.

Column 1 of Table 2 indicates which interruption period produced the greatest improvement in subjects' performance. Column 2 lists how much preparation time was given before the interruption. Column 3

shows the ratio of critical interest -- the length of the interruption period to the amount of time allowed for preparation.

Table 2

Ratios of Interruption Length to Preparation Time

Study & Result	Most Beneficial Interruption Length	Preparation Time	Ratio I:P
"Simple" Studies Reporting Benefit of Interruption Alone			
Fulgosi & Guilford (1968)	20 min.	2 min.	10:1
Fulgosi & Guilford (1972)	30 min.	2 min.	15:1
Silveira (1971)	210 min.	13 min.	16:1
Peterson (1974)	120 sec.	20 sec.	6:1
Beck (1979)	30 min.	12 min.	3:1
"Complex" Studies Reporting Benefit of Interruption + Another Factor			
Mednick et. al. (1964)	24 hr.	2 min.	1440:1
Dreistadt (1969)*	8 min.	5 min.	2:1
A. Patrick (1986)	4 min.	2 min.	2:1
Kirkwood (1984)	10 min.	10 min.	1:1
Dominowski&Jenrick (1972)	5 min.	5 min.	1:1
Murray & Denny (1969)	5 min.	5 min.	1:1
Studies Reporting Null or Negative Effects in All Conditions			
Gall & Mendelsohn (1967)*	25 min.	10 min.	3:1
Olton & Johnson (1976)	15 min.	10 min.	2:1
Studies Whose Design Prohibits Ratio Analysis			
Patrick (1935)			
Patrick (1937)			
Patrick (1938)			
Eindhoven & Vinacke (1952)			

* Ss in continuous work condition were allowed extra work time equal to the length of the interruption enjoyed by interrupted Ss.

The most striking result from Table 2 is that interruption alone appears to be beneficial when the ratio of interruption time to preparation time ranges from 6:1 to 16:1. When this ratio drops below 3:1, incubation can only be obtained when other facilitating factors are introduced (e.g., priming during the interruption period). Thus, the data in Table 2 suggest that there may be a lower bound on the length of the interruption period relative to preparation time if incubation is to occur. Since only one study has been done where this ratio is extremely large (Mednick et al., 1964), it would be premature to infer the existence of an upper bound on this ratio, although potential existence of both bounds should be explored in future experiments.

In sum, our analysis of the effects of length and timing of interruptions confirms the popular wisdom: Preparation is necessary for incubation to occur and the interruption must occur after an adequate preparation interval. However, the analysis goes further in that it suggests a relationship between the length of the incubation interval and the complexity of the task and preparation period. Although it is theoretically possible to specify an operational measure of complexity, for our purposes, we have made the simplifying assumption that experimenters implicitly took the complexity of their task into account in determining the length of the preparation period. In addition, some experimenters gave subjects more total time to work on the problems than did other experimenters. We found that the amount of total time given, which is a standard measure of task difficulty, was correlated highly (.94) with the amount of preparation time that was allowed. In general, longer preparation times were associated with longer total times. Having made these assumptions, it was possible for us to compare the length of the interruption with the length of the preparation period. This ratio varied over a narrow range of values for studies reporting simple incubation effects without the facilitating effects of other factors. Studies reporting null or negative effects typically had a much lower interruption:preparation ratio, suggesting that there may be a critical minimum length of the incubation period for a given task.

Nature of the Interruption

Critical to our distinction between simple and complex incubation effects is the nature of the activity that subjects perform during the period of interruption. Specifically, because many writers on the subject of incubation have suggested that interruption provides an opportunity for some new experience to happen that later helps problem solving, it is important to distinguish between interruption activities that are related and those that are unrelated to the problem.

Related activities include priming the subject, providing (subtle) hints, or having the subject engage in a

task that might be expected to provide positive transfer to the initial problem. Good examples of these types of studies are those done by Kirkwood (1984), Dreistadt (1969), Olton and Johnson (1976), and Gall and Mendelsohn (1967).

Kirkwood studied the effects of interruption on group-problem solving behavior. An instantiation of his experimental design follows: A continuous-work control group discussed the problem of how to improve student-faculty rapport for 30 minutes. A related interruption group discussed improving student-faculty rapport for 10 minutes, then discussed ways of creating a more friendly atmosphere among students for 10 minutes, and finally returned to the initial topic for 10 additional minutes. An unrelated interruption group was identical to the related interruption group except that the second topic of discussion was ways to reduce the amount of energy students use.

Kirkwood found (after scores were adjusted for problem difficulty) that subjects in the unrelated interruption condition produced significantly more solutions ($p<.05$, one-tailed) in their final ten minutes than did control subjects in the final ten minutes of their work. Kirkwood also reported a non-significant trend for the related interruption to produce more solutions than did continuous work. Based on these results, Kirkwood suggested that an incubation period may be beneficial only if the activity during the break differs from the initial task.

However, a major qualification of Kirkwood's results is in order. Most troublesome is the fact that both of Kirkwood's interruption groups were generating more solutions to the initial task even *before* the incubation period! Controlling for this initial advantage of the incubation groups, the incubation effect completely disappears.[5] Kirkwood suggests that the better performance of the interrupted groups may be due to the fact that they felt more pressured to generate solutions rapidly in the first 10 minutes since they knew they would be moving on to another task. However, we agree most strongly with Kirkwood's conclusions that "further research is needed to replicate the results of this study."

In contrast to Kirkwood's suggestion that activity during the interrupted period ought to be quite different from that of the primary task, Dreistadt's (1969) study suggests that similarity might be most helpful. Dreistadt had subjects work on one of two insight problems: the farm problem or the tree planting

[5]The method used was as follows: Determine the difference between the control group and an incubation group before the interruption by simple subtraction. Add this difference to the score of the incubation group after the interruption. Compare the adjusted scores.

problem.

For the Farm problem subjects were presented with a picture of a "farm" of dimensions nxn that had a square piece of dimensions .5n x .5n removed from one of the corners. The instructions were: "Divide the area of the farm into four parts which have the same size and shape." The tree planting problem consisted of ten arrows symbolizing trees along with the instructions: "Plant 10 trees in 5 rows with 4 trees in each row."

Subjects either worked on one of these problems continuously for 20 minutes (continuous-work groups) or worked for 5 minutes, guessed playing cards for 8 minutes, and then returned to the problem for an additional 7 minutes of work (interruption groups). Subjects in both groups were further divided into those who saw "pictorial analogies" and those who did not. The pictorial analogies consisted of three pictures for each problem that showed the shapes needed to solve the problem. Half of the interrupted subjects and half of the continuous-work subjects worked on their problem while these pictures stood in front of them on a Bristol board. The remaining subjects did not have the benefit of these pictures.

Dreistadt found that the pictorial analogies helped subjects solve the problems, regardless of whether subjects were interrupted. Moreover, in the case of the Farm problem, there was a significant interaction between pictorial analogies and interruption. That is, even though interruption alone was no better than continuous work, interruption combined with visual analogies was of more help than seeing the visual analogies in the continuous- work condition. On the basis of these results, Dreistadt suggests that incubation involves more than simple recovery from fatigue or the breaking of a mental set. An incubation period also provides an opportunity for subjects to find a new direction to pursue upon their return to the problem. Subjects exposed to the visual analogies were able to use the visual information in their environment (though not necessarily consciously) to generate a new approach to the problem. However, subjects in the more restricted visual environment had fewer opportunities to find a new problem-solving direction during the interruption.

It is noteworthy that Dreistadt found a benefit of interruption even though the interruption was **at the expense of** conscious work on the problem.[6] In effect, Dre ·'s results indicate that time spent during

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[6]As noted earlier, while most incubation studies compare the amount of work done before and after the interruption with an equivalent amount of continuous work, Dreistadt proposes a tougher comparison. He compares the total time spent by the incubation subjects (*including* the interruption period) with an equivalent amount of time spent in continuous work on the problem.

the interruption (in the pictorial-analogy condition) is **more productive** than the same amount of time spent consciously working on the problem. The implication is that incubation, at some level, involves processes different from those that are taking place during continuous problem solving. Specifically, Dreistadt suggests that breaking of set occurs, and that this process is useful when it occurs in an environment rich in material that is relevant to the problem.

Although quite striking, Dreistadt's results must be viewed in the context of Olton and Johnson's (1976) failure to replicate these results. Olton and Johnson's study is quite interesting in its own right, because in addition to attempting to replicate Dreistadt's finding that visual analogies plus interruption benefited performance on the farm problem, Olton and Johnson explored the effects of an entire range of interruption activities. Some subjects worked on the Farm problem continuously, but others were given demanding cognitive tasks during the interruption (e.g., the Stroop task and counting backwards by threes), or they listened to a lecture on set breaking, or they relaxed in a comfortable chair with soft music playing, or they were asked to review what they considered to be the important elements of the problem, or they simply did nothing but wait. Somewhat surprisingly, no incubation effects were found for any of the interrupted groups relative to the controls. In particular, these results differed from Dreistadt's in that Olton and Johnson found no benefit for interrupted groups that also had visual analogies made available.

Olton and Johnson's study differed from Dreistadt's in a number of ways. For example, Olton and Johnson's interrupted subjects worked for 10 minutes followed by a 15-minute interruption and 20 more minutes of work on the farm problem. Their control subjects worked continuously for 30 minutes. In contrast, Dreistadt's subjects worked for only 20 minutes (including the interruption -- if they were in an interruption group). By examining segments of their data that correspond in length to Dreistadt's conditions, Olton and Johnson were able to estimate the results of a more exact replication of Dreistadt's experiment. The conclusion is the same: The interrupted group does no better than the control group. In fact, there is a trend suggesting it actually does worse. One factor that cannot be accounted for is the difference in the length of the interruption periods in the two experiments (Dreistadt's 8 minutes versus Olton and Johnson's 15 minutes). However, it is difficult to see how this discrepancy would produce such different results.

The most likely explanation of the differences lies in the extremely good performance of Olton and Johnson's continuous work control-groups relative to that reported by Dreistadt. Olton and Johnson argue:

In Dreistadt's study, 70% of the subjects in the group with the prominent visual analogies solved the problem (in 13 min. of work time) and only 10% of the subjects in the control group did so (in 20 min. of work). The corresponding figures from the present study were 38% and 56% respectively, and when the standard [i.e. Olton and Johnson's] controls with 30 min total working time are used as a reference, the corresponding figures were 50% and 53%. Thus, regardless of which set of times is used, the performance of the controls in the present study was strikingly superior to the behavior of Dreistadt's controls. Indeed, given such high performance by a control group, even a treatment group that did achieve a solution rate of 70% might not differ significantly from it.

We are inclined to agree with Olton and Johnson's analysis of the discrepancy in results. However, without further research on the Farm problem, it would be difficult to determine which control group was exhibiting the anomalous behavior.

As a final example of how the nature of the interruption activity can affect incubation, consider the study by Mednick, Mednick, and Mednick (1964). Mednick et al. investigated the relationship between creativity (as measured by the Remote Associates Test), priming, and incubation. They gave subjects a series of three-word items such as *surprise line birthday* and asked the subjects to respond with a single associated word within a one minute time limit. For example, in this case, the answer would be *party*, because it can be combined with the stimulus items to form *surprise party, party line, and birthday party.*

Ten items that subjects failed to solve were presented again. Subjects were primed with the answer to half of these items during an interpolated task that involved solving analogies. The answers to some of the analogies were identical to the answers required to solve five of the difficult items that were presented a second time in the primary task. Mednick et al. found that subjects did significantly better in the primary task on the items that were primed during the interpolated activity, despite the fact that no subjects reported being aware of the connection. Inasmuch as Mednick et al. believed that one function of the incubation period is to introduce new associative elements, these results supported their hypotheses. However, the very short duration of the analogy task seems incongruous with what we might normally consider an incubation period. To address these concerns, as well as to explore the relationship between creativity as measured by the Remote Associates Test (RAT) and incubation, Mednick et al. conducted a follow-up experiment.

Their second experiment was similar to the first except that the interruption period between the end of the analogy task and the second presentation of the ten previously missed items was either 0 or 24 hours. For the 24-hour interruption conditions, half of the subjects received the prime before the

interruption and half received it at the end of the interruption. Again, it was found than primed subjects gave more correct answers that non-primed subjects, regardless of the length of interruption. Most striking, however, was the result that high and low scorers on the Remote Associates Test differed significantly in their performance after an interruption, without regard to priming. Whereas the positive priming results suggest that specific associative priming may be a component of incubation, Mednick et al. point out that some incubation occurred in the absence of priming. Even more intriguing is the fact that this simple incubation effect occurred mainly for the subjects with high scores on the Remote Associates Test.. This result suggests that incubation may be a phenomenon that is very much subject to individual differences -- a topic that we will take up shortly.

Table 3 lists the 13 studies that operationalized incubation as any benefit of interruption over continuous work. Also included are the primary tasks that were used, the variety of activities occurring during the interruption periods, and the outcome of the studies.

Table 3

Primary Tasks & Interruption Activities for 13 Studies

Study	Task Description	Interpolated Activity	Incubation?
Mednick et. al. (1964)	Remote Associates Test (RAT)	Analogy problems (relevant & irrelevant) & Free time	YES
Gall & Mendelsohn (1967)	Remote Associates Test (RAT)	Association training, or Psychophysical judgments	YES
Fulgosi & Guilford (1968)	Generate consequences in "what if" scenarios	Number series task	YES
Dreistadt (1969)	Farm & Tree Problems (insight problems)	Card guessing: W/ & w/o visual primes	YES
Murray & Denny (1969)	Saugstad's Ball Problem	Logical syllogisms, or Complex tracing task	YES
Silveira (1971)	Solve Cheap Necklace Problem	Read book, or Free time	YES
Fulgosi & Guilford (1972)	Generate consequences ("what if" scenarios)	Number series task	YES
Dominowski&Jenrick (1972)	Maier's Hatrack Problem	Free association, or Anagrams (w/ & w/o hints)	YES
Peterson (1974)	anagrams	Other anagrams that were also part of task	YES
Olton & Johnson (1976)	Dreistadt's Farm Problem	Various Combinations Of: Relaxation, Free time, Active review, Stroop task, Card guessing, Set breaking lecture, Visual primes, Counting backwards by threes	NO
Beck (1979)	Brainstorm for uses of "Luminium"	Relaxation, or Essay writing	YES
Kirkwood (1984)	Group brainstorming on campus life issues	Brainstorm: on related, or unrelated topic	YES
A. Patrick (1986)	Remote Associates Test (RAT)	Other RAT items: Alone, w/ conversation, or w/ mental rotation	YES

Individual Differences

Questions about incubation periods have generally been posed in terms of whether they facilitate problem solving. Researchers clearly disagree, with some of them finding facilitation (Fulgosi & Guilford, 1968, 1972; Peterson, 1971; Silveira, 1971) and others not finding it (Gall & Mendelsohn, 1967; Olton & Johnson, 1976). The literature on this topic is contradictory. We believe that part of the contradiction stems from individual differences in subjects' abilities to benefit from an incubation period. Unfortunately, even here the literature seems contradictory, with some studies showing that interruptions help high-ability subjects (Dominowski & Jenrick, 1972; Patrick, 1976) and some showing they have a slight effect (Mednick, Mednick, & Mednick 1964) or are even harmful (Murray & Denny, 1969).

We believe that the mixed results for incubation both as a main effect and as an individual differences variable derive from its being studied incorrectly. We will argue that whether incubation occurs depends not so much on the main effect of problem or subject, but on the person-problem interaction. Consider variables that are likely to enhance the effect of incubation periods and how they would depend on the interaction between problem and person.

A first such variable is the amount of processing that occurs during the incubation period. Some people may be more prone to thinking about problems than others, but the amount of processing probably depends on how a given person responds to a given problem. Many of us find, for example, that we ponder some kinds of problems and continue to be haunted by them, whereas other kinds of problems engender little effort. In problem solving, the very same problem that excites one person can leave another person cold. Thus, the amount of processing that occurs during an incubation period is likely to depend on how a given person reacts to a particular problem. How motivated a subject is will depend, in part, on the match between the subject's abilities and the abilities required by the problem (Sternberg, 1988). For example, subjects with high spatial ability might be more motivated to solve spatial problems, such as the farm problem (Dreistadt, 1969), than non-spatial problems, such as remote associations (Gall & Mendelsohn, 1967); Mednick, Mednick, & Mednick, 1964). Similarly, subjects who are divergent thinkers might dwell more on a divergent problem during an incubation period than they would on a convergent problem.

A second such variable is whether an individual has reached a dead end in problem solution or is on the path to a correct solution. If a person is at a dead end, an interruption seems likely to help by allowing time for useless associations to weaken and new, more useful associations to be formed (Mednick,

Mednick & Mednick, 1964). If, however, a person is on a productive route to solution, the person may be better off if allowed the time to pursue this route without interruption. In this particular case, an interruption may cause the person to lose track of where he or she is in problem solving. For example, Murray and Denny (1969) found that subjects with high scores on the Gestalt Transformation Test (GTT) performed better on a functional fixedness problem when they were allowed to work continuously. In contrast, subjects with low GTT scores benefited from an incubation period. Murray and Denny concluded that the incubation period disrupted the orderly search processes of the high-ability subjects and disrupted the maladaptive associations of the low-ability subjects. In short, where the person will be in problem solution depends on an idiosyncratic interaction of the person with the problem. An interruption might help some individuals but hurt others, depending on the kind of progress each person is making.

A third interactive variable involves whether an individual has been able to use whatever clues have been provided. If a person is trying out possibilities for use of a clue, an interruption might result in the forgetting of just what possibilities have been tried. Relevant features of the problem may need to be re-encoded or certain combined features may need to be recombined after the interruption. Some routes that have been tried may no longer be stored in working memory, with the result that these routes are tried yet again. If a person has reached a dead end with a particular clue, then the incubation period may help. For example, Dominowski and Jenrick (1972) found that subjects with high scores on the GTT performed better on the hatrack problem when a hint was given after an interpolated activity than when the hint was given during continuous work on the problem. In contrast, subjects with low scores on the GTT performed better when a hint was given during continuous work on the hatrack problem than when it was given after an interpolated activity. Dominowski and Jenrick suggest that the high-ability subjects had reached a dead end on the problem. When the hint was given in a neutral context it could be utilized quickly. However, the low-ability subjects had to become reacquainted with the problem before they could benefit from the hint. It seems likely that the low-ability subjects did not have enough relevant information in working memory to benefit from a hint given after interpolated activity. Notice that working memory storage, which may differ across problems depending on what each subject needs to store, may moderate the effects of an incubation period.

A fourth interactive variable is the knowledge a given individual brings to bear on a particular problem. In the hatrack problem, for example, someone with extensive experience using pole-lamps may have an

advantage. The more prior information one has, the less the problem may involve insight or a change in representation and the more it may involve somewhat routine combinations and recombinations of information until a solution is reached. In other words, more prior information may allow more continuity in problem solving. The individual can simply go through a series of familiar steps to reach solution. In such cases, an incubation period may not serve its desired function, because it will disrupt this continuity. If the relevant knowledge base is meager, however, then an incubation period may be more useful because it can lead to the generation of new solution paths that depend not on prior knowledge, but on redefinitions of the problem that occur only when an inappropriate set is broken. Breaking set can be facilitated by a period away from a problem.

In sum, we are arguing that it is probably a mistake to study incubation in problem solving without considering individual differences, but it is probably also a mistake to look at individual differences without considering the particular problems being solved. The usefulness of an incubation period may be largely determined by an interaction that has not been studied -- the person-problem interaction -- and not by the main effects of either problem or persons. We thus believe that future research on incubation, like much contemporary research in the personality area, should focus on interactions rather than on main effects.

Summary of Experimental Literature

The various studies reviewed in this article yield inconsistent and sometimes seemingly contradictory results. We shall argue that the complexity of the factors that influence incubation foreordains this seeming mass of confusion, given the designs of the studies. We are not criticizing these designs, but rather pointing out the complexity of the factors that determine whether an incubation period will facilitate problem solving.

First, incubation requires that an individual be far enough along towards the problem solution for certain beneficial processes to operate. If the incubation period starts prematurely, there will be insufficient mental contents for the process to be profitable. Thus, time until the incubation period begins will affect the usefulness of a period of incubation. The time function is unlikely to be strictly linear. If preparation time is insufficient, then mental contents will be insufficient (Silveira, 1971). But if too much time is allowed, at least some subjects will have reached solutions or be close to them, so that incubation will no longer be profitable. Thus, too little or too much time is likely to reduce incubation effects.

The length of the incubation period will also make a difference. If too little time is given, then maladaptive problem associations will not have time to decay (Fulgosi & Guilford, 1968). If too much time

is given, then fatigue or interference from the intervening task might negatively influence problem solving (Fulgosi & Guilford, 1972).

Second, how much time is the "right" amount of time to observe incubation effects will be affected by problem difficulty, measured either in terms of average time to problem solution or proportion of subjects eventually reaching solution. On the average, more difficult problems will need more preparation time prior to incubation time in order for sufficient mental contents to be generated for an incubation period to have a positive effect.

However, difficulty of an insight problem is not a unidimensional construct, despite the fact that the interaction of sources of difficulty can yield a single measure of difficulty, such as average time to solution. Difficulty involves, psychologically, the obscure nature of the correct solution path in contrast to the obviousness of incorrect, and hence distracting, solution paths. In some insight problems, it is simply hard to see the correct path. In others, distinguishing relevant from irrelevant information plays more of a role; alternate solution procedures may lead subjects down garden paths. It may take different amounts of both preparation and incubation time to arrive at the correct path, as opposed to ruling out incorrect paths. Thus, in order to determine the proper length of preparation and incubation periods, one would need to know not only the difficulty of a given problem but the sources of difficulty. In other words, one would have to do an accurate and fairly detailed task analysis.

Third, one could not do such a task analysis or establish time constraints accurately in the absence of an analysis of individual differences. Some subjects may need more preparation time, or more incubation time, as a function of their abilities. Subjects' abilities to profit from primes and prior knowledge will determine the benefits of an incubation period.

Non-cognitive individual-differences variables will also affect differential problem difficulty for various subjects (Sternberg, 1988). Motivation to solve the problem, persistence in seeking out a solution in the face of initial negative results, and willingness to tolerate the ambiguity of seeming to get nowhere in solving an insight problem will differentially affect subjects' ability to make use of an incubation period.

Fourth and finally, as the studies cited in this article show, the situation in which the problem is presented and in which the incubation period is embedded will affect the fruitfulness of an incubation period. Subjects may be able to utilize an incubation period differentially well inside versus outside a

laboratory setting. Indeed, a number of investigators have shown fairly drastic differences inside versus outside laboratory settings (see, e.g., Rogoff & Lane, 1984; Sternberg & Wagner, 1986). Moreover, the kind of task being performed during the incubation period, as well as its direct or indirect relevance to the solution of the problem, are likely to influence just how helpful an incubation period will be. If subjects need to break fixation on inappropriate strategies, then an unrelated interpolated activity may help them (Patrick, 1986). If subjects are searching for new strategies, then a related interpolated activity or hints may help them (Dreistadt, 1969; Dominowski & Jenrick, 1972; Mednick, Mednick, & Mednick, 1964).

To make matters even more complicated, the variables discussed above may be interactive, rather than strictly additive. For example, some subjects may profit more from a priming situation than others if their knowledge is organized in a way that renders priming more effective. Also, subjects may simply differ in the typical speed with which they access and exploit information (see, e.g., Hunt, 1978; Sternberg, 1977), resulting in a given amount of time profiting some subjects more than others.

In short, a multiplicity of variables and their interactions will affect the results of experiments involving varying amounts of preparation and incubation times, resulting almost inevitably in the kinds of seeming contradictions that have so far been obtained in the literature. These interacting variables will generate the appearance of contradictory findings when, at a psychological as opposed to a behavioral (and hence observable) level, such contradictions may not exist. A full understanding of incubation will require an understanding of how these variables operate, independently and in interaction.

Towards a Unified Theory of Incubation

Earlier in this paper we argued that conceptualizing incubation in terms of mechanisms would help us understand incubation effects. However, our discussion of individual differences makes clear that mechanisms are only half of the story. Any comprehensive theory of incubation must also take into account task and subject variables as well. Only in the context of such a unified theory will the diverse empirical literature begin to have cohesion. Such cohesion is vital if research on incubation is not to degenerate into clusters of isolated experiments reporting apparently contradictory results.

We propose the following framework, not as a complete and comprehensive theory of incubation, but rather as an illustration of the direction we hope future research on incubation will take.

Our unified theory begins with the key issue of problem difficulty and adopts the widely known

conception of problem solving as search through problem spaces (Newell & Simon 1972, Newell 1980). Within this search framework, there are at least three ways that a problem might be hard:

1. The problem solver may have **too many paths** and no good way of deciding which path to choose.

2. The problem solver may be completely **unable to generate any new paths**, and can only stare blankly at the problem.

3. The problem solver may be capable of generating a number of different paths, but suffers from **stereotypy**. That is, the problem solver persists is generating paths only from a narrow set.

We suggest that the same variables which we have discussed as influencing incubation might have their effect primarily by determining which of these three types of difficulties a problem solver is likely to encounter. For example, a relevant dimension of the *primary task* variable is the branchiness of a task's search space. A task with a large, well defined search space, like chess, often is difficult because there are **too many paths**. Anyone who knows the rules can always generate moves exhaustively. The difficulty lies in choosing which paths to explore.

In contrast many insight problems typically have points at which the subject cannot think of anything to do next. In these cases, the obstacle is of the type **unable to generate any paths**. Some insight problems (e.g The Mutilated Checkerboard Problem, Kaplan & Simon 1988) are difficult because they trick subjects into trying the wrong approach at first. Subjects typically suffer from stereotypy as they repeatedly try slight variations of this seductive, but incorrect, approach. Eventually the subjects become frustrated but are unable to think of anything new. Hence, it is quite possible for both stereotypy and inability to generate new paths to occur in the same problem at different times.

Such timing considerations provide a clue as to why the length of the preparation interval may be an important variable in incubation experiments. If a subject is interrupted quite late, he or she may have already passed through a period of stereotypy and now may be unable to generate new paths. Given the hypothesis that the helpfulness of an interruption depends critically upon the type of difficulty a subject is experiencing, it follows that, for some problems, incubation effects should depend upon the timing of the interruption.

Individual differences are also likely to affect the type of obstacles subjects encounter during problem solving. Differences in knowledge allow one subject to suffer from stereotypy (repeated application of

inappropriate knowledge) while another subject, perhaps lacking this inappropriate knowledge, may suffer from an inability to generate any options at all. Such differential effects of knowledge have been documented in the case of at least one insight problem (Kaplan & Simon 1988). It is easy to imagine how other individual differences -- for example differences in the ability to generate new paths -- might result in some subjects having too many paths to choose from, while others are unable to generate any new paths at all.

Mechanisms X Problem Difficulty

To account for the range of incubation effects reported in the literature, we need to consider the interaction between a given mechanism for incubation and the specific type of difficulty that a subject experiences. In particular, we will focus on the mechanisms of priming and forgetting (decay of activation) because they can account for most, if not all, of the empirical results, once their interaction with problem difficulty is understood. For the sake of simplicity, we will also consider only the two types of difficulty that are most characteristic of insight problems: The inability to generate any paths, and Stereotypy. Table 4 shows the critical predicted interactions.

Table 4

Predicted Interactions Between Problem Difficulty Type & Mechanisms

	INABILITY TO GENERATE NEW PATHS	STEREOTYPY
Priming	Best chance of helping. Ss are in a receptive state.	No help at all. Ss are preoccupied and not receptive to a subtle prime
Forgetting	Will not help at all. There is nothing to forget. (Assuming past responses are not creating "blocking" to associative interference)	Should help a lot. Activation of most dominant response will decay, allowing consideration of other responses.

We envision both priming and forgetting as occurring within a spreading activation model of human memory (Anderson 1983). When a prime is presented, the activation levels of associated information in long- term memory increase. If the prime is strong enough, the activation levels may cross a threshold and enter working memory. Otherwise, the ease with which the information can enter working memory, or equivalently the probability of retrieving that information, increases in proportion to the strength of the prime.

Forgetting can occur in two ways, both explainable in terms of a spreading activation model. First, the activation level of information in long-term memory is always decaying towards some baseline rate. So, the passage of time alone is sufficient to cause forgetting. In addition, because of the fan effect, the activation of new (previously inactive) information can make it harder to recall other information that is quite similar (Anderson 1981).

A prime should help most when a subject is unable to generate any new paths, since attention is more likely to be focused on the prime and there is little activation of competing information. A prime should be of no help, however, if the subject is strongly focused on another path, as in the case of stereotypy.

In contrast, forgetting should help subjects suffering from stereotypy because it provides an opportunity for the activation of these misleading paths to decay. Conversely, forgetting should be of little help if the subject is simply unable to generate any new paths. Assuming that the subject has simply run out of things to try, there is nothing to forget.[7]

Accounting for the Data

One problem that any unified theory of incubation must face is dealing with the relatively sparse data about the *process* of problem solving. Perhaps the best way to determine the type of difficulty a subject is experiencing during problem solving is to obtain concurrent verbal reports by asking subjects to think aloud as they work (Ericsson & Simon, 1984). Unfortunately, protocol data have not been reported in thirteen of the seventeen studies. We must therefore do the best we can with the data at hand, recognizing that many "ifs" will exist which will have to be verified by the results of future experiments. Since our aim is to illustrate the direction in which further research should move (namely towards unification in general), we will not be overly concerned at this stage about the gaps that currently exist.

How well might our unified theory account for the empirical results we have already discussed? First, we should restrict the list of studies to those which do not already have clear explanations, in terms of already established processes besides forgetting and priming. Studies which we can eliminate on these grounds are those of Catherine Patrick (1935, 1937, & 1938), Eindhoven and Vinacke (1952), Gall and Mendelsohn (1967), Olton and Johnson (1976), and Kirkwood (1984).

[7] If it turns out that the subject cannot generate new options because some information is blocking this generation process, then we would expect forgetting to help. However, whether inability to generate new paths is a function of such blocking or simply exhaustion of ideas will probably depend upon the problem and the subject's current state in problem solving.

In the case of the studies by Patrick (1935, 1937, 1938) and Eindhoven and Vinacke (1952), incubation was defined differently from the way it has been used in this paper. Patrick considered incubation to be simply "the recurrence of ideas" during problem solving. Because the problem-solving strategy of **best first search** leads to recurrence of ideas, this definition of incubation can be accounted for in terms of conscious problem solving. Eindhoven and Vinacke define incubation as "thought about the problem, conscious or not" and present no evidence that anything other than normal problem solving is occurring.

The major finding of Gall and Mendelsohn (1967) regarding incubation was that continuous work on the primary task was more beneficial than time spent on an unrelated psychophysical judgment task. Note that this comparison is different than the typical comparison of total time T spent in continuous work versus the same time T divided into two work periods which are separated by an **additional** interruption period. The mechanisms of forgetting and priming would need an exceptional opportunity to have an effect if the time spent during an interruption period is to be more useful than the same time spent in conscious work (see the discussion of Dreistadt's experiment below). Gall & Mendelsohn provided no such opportunities in their design. The interpolated judgment task was specifically chosen so as to minimize interference with the primary task. However, such a choice also tends to minimize the *likelihood* of forgetting. Moreover, since the interpolated judgment task was completely unrelated to the primary task, the opportunity for priming was negligible. Considering these conditions, the experimental finding that more conscious work is better seems just what one would expect.

Their other interesting finding, that free association for females interacting with female experimenters was approximately equal in benefit to conscious work, also seems reasonable. To begin with, the difference between free associating to RAT items and actually working on RAT items is potentially quite small. Once social psychological factors concerning inhibitions about free associating in the presence of an experimenter of the opposite sex are taken into account, that slight difference might reasonably disappear altogether as Gall & Mendelsohn report. Again the results seem entirely consistent with psychological principles independent of any incubation mechanisms.

We have already discussed at length how the high performance of the control group in Olton and Johnson's study makes their results difficult to interpret. Since most of his interrupted groups perform as well as the controls and since the reason for the good performance of the controls awaits further replication attempts, we are left with the task of explaining the exceptionally poor performance of two incubation groups: the stress *reduction group*, and the set breaking lecture plus unobtrusive visual

analogies group. Subjects in the former group listened to classical music and were encouraged to relax. We conjecture that some of them may have relaxed too much and lost motivation by the time they returned to the primary task. The group that received a lecture on set breaking was presumably motivated to search for new approaches to the problem. This attitude would have been helpful except that Olton & Johnson provided them with an array of "unobtrusive pictures", most of which were completely irrelevant to the problem. It is quite possible that subjects did look for new approaches but had a high probability of finding misleading ones in the irrelevant pictures.

With a final exclusion of Kirkwood's study due to the major flaws that were discussed earlier, we can begin an account of the results of the remaining studies (including some results which were previously unexplained) in terms of our unified approach.

Fulgosi and Guilford (1968, 1972), Silveira (1971), Peterson (1974), and Beck (1979) report incubation results that can be interpreted fairly simply as forgetting interacting with stereotypy. Table 2 shows that these five studies all had relatively high ratios of incubation time to preparation time. A high ratio is just what we would expect if time were needed for the activation of inappropriate information (i.e., information leading to stereotypy) to die down. Thus, a simple forgetting, or decay of activation, mechanism may be able to account for the positive reports. In certain conditions of the experiments where incubation effects failed to occur, the reason can be traced to an interruption that was too short (relative to the needed preparation time) for much decay to occur (Fulgosi & Guilford 1968, Silveira 1971, Beck 1979), to a lack of adequate preparation period (Silveira 1971), or to the negative effects of fatigue resulting from long work at a very difficult interruption task (Fulgosi & Guilford 1972).

Dreistadt (1969) reports results that can be interpreted most simply as priming. Interrupting work on the farm problem for eight minutes of card guessing did not lead to any incubation effects because a) the interruption was short relative to the required preparation time, b) the continuous-work subjects got an extra eight minutes of conscious work on the problem which ought to more than offset the minimal benefits of forgetting over such a short interruption interval. On the other hand, presenting a subtle relevant prime (in the form of pictures) to the subjects while they worked on the problem did lead to better performance as we might expect. The fact that the pictures were present throughout the problem solving episode increased the probability that subjects would notice the prime when they reached a point of inability to generate new options -- the point at which we hypothesize subjects ought to be most receptive to such a prime. Finally, Dreistadt reports an interaction between an interruption period and priming such

that the highest number of subjects solved the problem when they received both a break and were exposed to the pictures. This interaction can be understood when we consider that the interruption period is likely to have increased the probability of noticing the pictures. Thus priming remains the mechanism that explains incubation, but an interruption can increase the probability of noticing a subtle prime.

The results of Murray and Denny (1969) and Dominowski and Jenrick (1972) appear at first to be in direct contradiction. Murray and Denny report that low ability subjects benefit from an interruption, whereas high ability subjects perform best if allowed to work continuously. In contrast, Dominowski and Jenrick report that "For Ss of high ability, the hint produced slightly faster solutions when given after a period of interpolated activity while low ability Ss made better use of the hint when it was given during continuous work." We believe the words "ability" and "hint" are the keys to resolving the apparent conflict in results.

We would essentially agree with Murray and Denny's analysis of their results. They attribute the beneficial effect of an interruption for low ability subjects to forgetting, arguing that "their problem solving processes may have been characterized by initial blocking or fixation on stereotyped responses to the available objects." Since Murray and Denny collected verbal protocols, presumably they are better equipped to make such a judgment than other experimenters without such data. They further argue that high ability subjects were disrupted by the interruption. Since subjects had no fixations to forget, and because the preparation was relatively short (5 minutes), this interpretation also seems reasonable to us. In short, forgetting should help only if stereotypy is the source of difficulty. In Murray and Denny's experiment, it seems likely that only the low ability subjects suffered from stereotypy.

Turning to the results of Dominowski and Jenrick (1972), we note first that low ability (again measured by the GTT) subjects benefited from a hint only after an interpolated activity. This is not surprising because low GTT Ss are those most prone to stereotypy. Our theory predicts that such subjects will be unable to benefit from a hint (because of their fixation on incorrect approaches). However, if time is allowed for the fixation to decay then the subjects should no longer suffer from stereotypy and the hint should lead to beneficial effects. On the other hand, subjects **not** suffering from stereotypy (i.e., the high GTT subjects) should be able to use the hint effectively without any need for an interruption period. If anything, the interruption might be slightly detrimental as it would force them to do some recoding of the problem when they return from the break. This explanation fits precisely the results reported by Dominowski and Jenrick. In short, the same general theory of priming and forgetting interacting with

types of problem difficulty has potential for explaining what up until now were seen as contradictory findings.

Our final concern will be to suggest how a unified theory might be able to explain findings which have been previously unexplainable. Both Mednick et al. (1964) and Andrew Patrick (1986) conducted incubation studies using the Remote Associates Test (RAT) as the primary task. Both found results which were somewhat puzzling, but which we feel might be understandable using a more unified approach.

Table 5 shows the results Mednick et. al. reported, adapted from their Table 1 (Mednick et al. 1964, p. 87).

Table 5

Results adapted from Mednick et. al., 1964

Mean Number of Remote-Associates Items

Correct Following Incubation

Incubation	High RAT ability		Low RAT ability	
	Relevant Prime	Irrelevant	Relevant Prime	Irrelevant
Immediate prime	1.50	0.50	0.50	.25
Prime followed by 24 hr. break	1.50	1.00	0.25	.50
24 hr. break 1st then prime	1.75	1.00	0.75	.25

Earlier we noted that these results confirmed the efficacy of priming and raised some unanswered questions with regard to individual differences in ability. Specifically Mednick et. al. concluded:

The small amount of incubation that did occur in the absence of specific [relevant] priming has not been explained and needs further study, as does the fact that the high RAT scorers seem to incubate more readily than do the low scorers.

That is, why should high ability Ss benefit from an interruption without a relevant prime (column 2) whereas low ability subjects show no such benefit (column 4)?

Considering that the RAT measures ability to generate remote associations to a stimulus it seems reasonable that high ability subjects would generate more potential candidates and, thus, experience more associative interference than low ability subjects. The mechanism of forgetting, or decay of

activation, would therefore help the high RAT subjects more than the low RAT subjects, explaining the observed difference.

A more complex puzzle is why priming appears to help high ability Ss (column 1) more than low ability Ss (column 3). Our theory suggests that we turn to an interaction between priming and forgetting for an explanation. First, an immediate (relevant) prime is better than no (relevant) prime (row 1). We would view this result as the straightforward beneficial effect of priming with high ability Ss possibly being more sensitive to primes as Mednick et al. (citing Mendelsohn and Griswold 1964) suggest.

Now, when the prime is followed by a 24-hour break, its activation should decay, and its benefit should decrease correspondingly. The performance of both subjects should be hurt, and indeed the the low ability Ss seem to suffer (column 3, rows 1 & 2). However the high ability Ss receive a benefit due to forgetting that we have argued the low ability Ss should not enjoy. If the benefit due to decay of associative interference offsets the detriment due to decay of the prime then the high ability Ss will perform as well after a 24 hr. break as they did when they got an immediate prime (column 1, rows 1 & 2).

Consistent with this account is the prediction that high ability Ss should do best when the prime *follows* a 24 hr. break, since they would reap the benefits of **both** forgetting and priming. Table 5 (column 1, row 3) verifies this prediction. The low ability subjects appear to reap some of these same benefits (column 3, row 3). However presumably the benefit is due mainly to priming as argued above.

The point of performing this rather detailed analysis is to demonstrate how a unified theory involving both forgetting and priming can account for results that seem puzzling when either mechanism is considered in isolation. The power comes from considering interaction of factors which sometimes act in opposite ways simultaneously. Without going into too much detail, we suggest that an account similar to the one given above might explain the somewhat puzzling results of Patrick (1986).

Briefly, Patrick's results suggest that subjects of high RAT ability perform better on RAT items when they have longer breaks, and when these breaks are of an increasingly non-verbal nature. We suggest these conditions maximize potential for decay of associative interference. On the other hand, subjects of low RAT ability, who presumably suffer less from associative interference, do not benefit much from forgetting. However, they could benefit from priming. We suggest that circulating through the RAT problems continuously serves to prime new possibilities for low ability subjects whereas such circulation

(without an additional break) acts primarily to prevent the decay of interference for the high ability subjects. Once one assumes that the mechanisms of priming and forgetting may be differentially affecting low and high ability subjects in different conditions, the results reported by Patrick appear much more understandable.

Conclusions

We believe that the incubation effect is a real, but complex, one. An incubation period can serve several functions; how well it serves them will depend upon a number of interacting variables. These include the nature of the primary task, the timing and length of the interruption, the nature of the activity performed during the interruption, and individual differences in the knowledge and abilities of subjects.

Because these variables can interact in complex ways, experiments done to date are contradictory. It would take much more knowledge than we now have to disentangle unambiguously the effects of time, problem difficulty, individual differences, and interpolated tasks upon incubation. But we believe that further work on solving the problem of incubation requires as a prerequisite a recognition of just what the problems are that are associated with the phenomenon and *its study*. *Without such problem recognition*, researchers will go on indefinitely obtaining inconclusive and seemingly contradictory results.

We have argued that a good way to address the complexities of incubation research is to strive for a unified theory of incubation phenomena. We proposed one such theory to illustrate the potential power of a unified approach. While strong claims for the accuracy of this particular theory would be premature, the attention paid to mechanisms and interactions between factors seems a step in the right direction. Much research needs to be done on the way towards an empirically tested unified theory of incubation. However, we believe the goal is attainable. We hope this article will serve as a useful starting place.

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